

The contribution of $\Sigma^* \rightarrow \Lambda\pi$ to measured Λ polarization[†]D. Ashery¹

and

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² *Department of Particle Physics**The Weizmann Institute of Science, 76100 Rehovot, Israel***Abstract**

Calculations of the polarization of Λ and $\bar{\Lambda}$ particles after fragmentation of a polarized quark produced in processes like Z -decay and deep inelastic polarized lepton scattering must include Λ and $\bar{\Lambda}$ produced as decay products of Σ^0 and Σ^* as well as those produced directly. These decay contributions are significant and not feasibly included in theoretical calculations based on QCD without additional input from other experimental data. Furthermore these contributions depend on the spin structure of the Σ^0 or Σ^* and are not directly related to the structure function of the Λ

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The interpretation of studies of the nucleon spin structure functions is that quarks in the nucleon carry only $\sim 30\%$ of the nucleon spin and that the strange (and non-strange) sea is polarized opposite to the polarization of the valence quarks. An attempt to shed light on this very problematic conclusion was made through measurement of the polarization of Λ and $\bar{\Lambda}$ produced near the Z pole in e^+e^- collisions [1, 2] and in polarized lepton Deep Inelastic Scattering on unpolarized targets [3, 4]. Several theoretical works were published on this subject in which predictions and calculations relevant to the interpretation of the experimental results were presented [5, 6, 7, 8, 9, 10, 11, 12]. A difficulty present in most experiments is that they cannot distinguish between Λ and $\bar{\Lambda}$ produced directly or as decay products. The main contribution from decays is the $\Sigma^* \rightarrow \Lambda\pi$. The purpose of the present note is to emphasize the importance of taking into account the contribution from this process.

To illustrate this point, if 100% polarized strange quarks hadronize directly to a Λ , the Λ polarization will be also 100% if the spin structure of the Λ is as expected by the naïve quark model. On the other hand, if they hadronize to a Σ^* the Λ particles resulting from its decay will be only 55% polarized [12]. If the spin structure of the Λ is as derived from SU(3) symmetry using the measured spin structure of the proton, 100% strange quarks will result in 73% polarized Λ if produced directly compared with the same 55% if coming from Σ^* decay.

The polarization of the Λ particles observed in any experiment can be written

$$P(\Lambda) = \frac{N_{nd} \cdot P_{nd}(\Lambda) + N_{\Sigma^*} \cdot BR(\Sigma^* \rightarrow \Lambda\pi) \cdot P_{\Sigma^*}(\Lambda) + N_{\Sigma^o} \cdot P_{\Sigma^o}(\Lambda)}{N_{\Lambda}} \quad (1)$$

where N_{Λ} , N_{Σ^*} and N_{Σ^o} denote respectively the numbers of Λ 's, Σ^* 's and Σ^o 's produced in the experiment, $BR(\Sigma^* \rightarrow \Lambda\pi)$ denotes the branching ratio for the $\Sigma^* \rightarrow \Lambda\pi$ decay, $P_{\Sigma^*}(\Lambda)$ and $P_{\Sigma^o}(\Lambda)$ denote respectively the polarizations of the Λ 's produced via the $\Sigma^* \rightarrow \Lambda\pi$ decay and the $\Sigma^o \rightarrow \Lambda\gamma$ decay, and N_{nd} and $P_{nd}(\Lambda)$ denote the number and polarization of Λ 's produced via all other ways; i.e. which do not go via the Σ^* or Σ^o ,

$$N_{nd} = N_{\Lambda} - N_{\Sigma^*} \cdot BR(\Sigma^* \rightarrow \Lambda\pi) - N_{\Sigma^o} \quad (2)$$

The individual terms in the numerator of eq.(1) are all distinct and measurable. Any calculation of the polarization of the final observed Λ must consider all these contributions if they are not separated experimentally.

One might argue that the $\Sigma^* \rightarrow \Lambda\pi$ decay is a strong interaction described in terms of quarks and gluons in QCD and should be included in the inclusive polarized fragmentation function. Clearly the Σ^* intermediate state must be already included in any fragmentation function which takes into account *all* strong

interactions in the description of a process in which a struck quark turns into a Λ plus anything else. This point of view is implied in the treatments [5, 6] which attempt to use the Λ polarization data to extract fragmentation functions. But the expression for the Λ polarization eq.(1) is rigorous. Thus a theoretical formulation which gives a prediction for this polarization must also include a prediction for the precise values for all parameters appearing in eq.(1)

We immediately find a crucial weak point in all attempts to obtain a theoretical estimate for the value of the Λ polarization. Any theoretical attempt to obtain the value of the branching ratio $BR(\Sigma^* \rightarrow \Lambda\pi)$ must take into account fine threshold effects like the small SU(3) breaking produced by the $\Lambda - \Sigma$ mass difference which vanishes in the SU(3) symmetry limit. Note that in the SU(3) symmetry limit the predicted ratio of the branching ratios of the two Σ^* decay modes is in strong disagreement with experiment:

$$\left(\frac{BR(\Sigma^* \rightarrow \Lambda\pi)}{BR(\Sigma^* \rightarrow \Sigma\pi)} \right)_{theo} = 1/2 \neq \left(\frac{BR(\Sigma^* \rightarrow \Lambda\pi)}{BR(\Sigma^* \rightarrow \Sigma\pi)} \right)_{exp} = 7.3 \pm 1.2 \quad (3)$$

The disagreement is more than an order of magnitude.

There is also the problem of obtaining the values of N_{nd} , N_{Σ^*} and N_{Σ^o} . If one assumes a purely statistical model in which all states of two nonstrange quarks and one strange quark are equally probable the ratio

$$N_{nd}/N_{\Sigma^*}/N_{\Sigma^o} = 1 : 6 : 1 \quad (4)$$

where the factor 6 arises from the $(2J+1)$ spin factor and the three charge states of the Σ^* which all decay into $\Lambda - \pi$. The experimental values are very different. There is also the problem that all three charge states are equally produced by the fragmentation of a struck s quark, while a struck u or d quark can only produce the two charge states containing the struck quark. All these factors complicate any attempt at this stage to predict values of N_{nd} , N_{Σ^*} and N_{Σ^o} from any purely theoretical model without any external experimental input.

Thus predictions for polarization of the Λ 's observed in any experiment must include as input the known experimental branching ratio $BR(\Sigma^* \rightarrow \Lambda\pi)$ as well as the values of N_{nd} , N_{Σ^*} and N_{Σ^o} obtained from other experiments or from Monte Carlo programs which rely on a number of free parameters which are adjusted to fit vast quantities of data. Note that the Σ^o decays electromagnetically. Its decay is never included in any strong interaction fragmentation function and the Λ 's produced via its production and decay must be considered separately in all fragmentation models.

We now note that the polarization of Λ produced from the decay of a Σ^* or Σ^o is proportional to the polarization of the decaying Σ^* or Σ^o with coefficients depending only on angular momentum Clebsch-Gordan coefficients and completely

independent of the spin structure of the Λ [12]:

$$P_{\Sigma^*}(\Lambda) = P_{\Sigma^*} \cdot C(\Sigma^*); \quad P_{\Sigma^o}(\Lambda) = P_{\Sigma^o} \cdot C(\Sigma^o); \quad P_{\Sigma^* \Sigma^o}(\Lambda) = P_{\Sigma^*} \cdot C(\Sigma^* \rightarrow \Sigma) \quad (5)$$

where P_{Σ^*} and P_{Σ^o} denote the polarizations respectively of the Σ^* and Σ^o before their decays, and $C(\Sigma^*)$, $C(\Sigma^o)$ and $C(\Sigma^* \rightarrow \Sigma)$ denote the model-independent functions of Clebsch-Gordan coefficients describing the ratio of the polarization of the final Λ to the polarization of the decaying baryon. The explicit values of these functions are given in ref. [12], where it is shown that the polarization of the final Λ in all models for the baryons and the dynamics of the decay process is given by the polarization of the strange quark in the simple constituent quark model for the decaying baryon. We immediately note that only the polarization of the directly-produced Λ can depend upon the spin-flavor structure of the Λ . The other terms in eq.(1) depend upon the spin-flavor structure of the Σ^* and the Σ^o , but are independent of the spin-flavor structure of the Λ .

The expression eq.(1) for the polarization of all the Λ 's produced in a given experiment is easily generalized to obtain the polarization of Λ 's restricted to a given domain of various kinematic variables. It is necessary to note that the momenta of Λ 's produced from a decay of a Σ^* or Σ^o are different from those of the parent baryon. Thus to obtain the polarization of Λ 's produced in a given kinematic range one must integrate the expressions for N_{Σ^*} and N_{Σ^o} over momenta with the appropriate weighting factors and angular distributions needed to produce the Λ 's in the correct kinematic range. All this cannot be done reliably in present theoretical calculations and has to be taken from Monte Carlo simulations that are tuned and tested and thus reproduce well many related experimental observables.

The polarization of Λ and $\bar{\Lambda}$ produced at the Z-pole [1, 2] was calculated using two ingredients: the polarization of the s and \bar{s} quarks produced at the pole and their hadronization into Λ and $\bar{\Lambda}$. The first part was derived from weak interactions [5] and can be predicted directly. The hadronization of the s, \bar{s} directly to Λ and $\bar{\Lambda}$ or as decay products was calculated using Monte Carlo simulations. The authors found that about 20% of the Λ polarization is contributed by Λ particles originating from Σ^* decay. These calculations used the naïve quark model wave functions for the baryons. This shows that inclusion of this contribution was essential for obtaining agreement with the data. In any attempt to go beyond the naïve quark model and include the information obtained from DIS on the spin-flavor structure of the proton, it is clearly necessary not only to have a model for the spin-flavor structure of the Λ , but also of the Σ^* and the Σ^o as well.

In studies of Λ polarization in deep inelastic scattering of polarized muon [3, 12] the x_F dependence of this contribution is studied (see fig. 1). It is found that up to $x_F \sim 0.5$ the contribution from Σ^* decay to the Λ polarization is

dominant. It is only for larger x_F values that polarization from directly produced Λ 's becomes dominant. It should be noted that the Λ yield is dropping fast for large x_F and consequently most of the data is taken in the region where the Λ polarization is dominated by Σ^* decay. The contribution from this process must therefore be considered very carefully. This contribution was addressed only in some of the theoretical calculations of this process [10, 11, 12].

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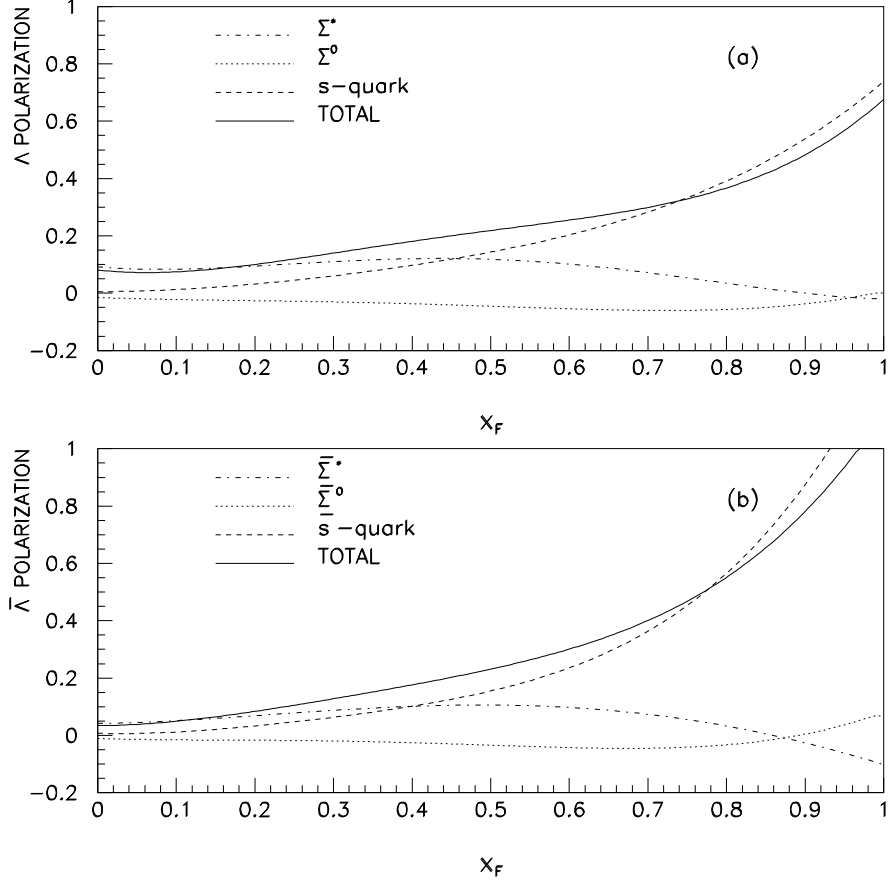


Figure 1: Polarization of Λ (a) and $\bar{\Lambda}$ (b) hyperons. Contributions from direct production (dashed line), from decays of Σ^0 (dotted line), of Σ^* (dash-dotted line) and the total polarization (solid line). All are calculated using the naïve quark model.